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ABSTRACT

This paper reports two experimental studies of the development of time, speed and distance concepts in children. In Experiment I subjects (12 in each of four age groups: 5-, 8-, 11-year-olds, and adults) were asked to judge which of two electric trains on parallel tracks went faster, for the longer distance, or for more time. Subject's knowledge of each concept was assessed by a method which assumes that cognitive development can be characterized as a set of rules. Two questions were addressed: what are the knowledge states leading to the understanding of the concepts and in what order are the concepts mastered. Results indicate that 5-year-olds equate time, speed and distance with the relative stopping points of moving objects. Adults possess full understanding of the three concepts. Many children mastered both the speed and distance concepts by age 8 and the majority mastered both by age 11. The time concept appears to be mastered sometime between age 11 and adulthood. Experiment II explored the use of rule assessments to predict ability to respond to different types of training. A pretest, feedback training, posttest procedure was followed. It is concluded that it is possible to predict differences in children's ability to acquire new knowledge once their inital knowledge states can be specified. (Author/RH)

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The Development of Time, Speed, and Distance Concepts

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In 1928, Albert Einstein questioned Jean Piaget about children's understanding of speed and time. The questions arose because relativity theory produced a fundamentally different view of these concepts than classical Newtonian mechanics. Einstein wanted to know which concept children understood first, whether they understood either or both concepts "intuitively," and how the development of one concept influenced the development of the other.

Piaget's two-volume answer to these questions (Piaget 1946a/1969; 1946b/1970) posited that time, speed, and distance each underwent a 3-stage developmental progression. Stage I children equated each concept with a single spatial dimension; thus, if two cars traveled along parallel tracks, the car that stopped farther ahead would be said to have traveled for the longer time, at the faster speed, and for the greater distance. In Stage II other factors such as starting point began to be considered. Stage III represented mastery of each concept.

Despite the fact that Piaget claimed that children master time, speed, and distance simultaneously, he appears never to have examined the same children on all three concepts. In addition, his assessment methods for the three concepts were not fully comparable. Subsequent studies (Berndt and Wood, 1974; Friedman, 1978; Levin, 1977; and Weinreb and Brainerd, 1974) have expanded our understanding in several regards, but have not delineated the sequence of knowledge states leading to mastery of each concept, and have not compared the ages at which children master the three of them.

Experiment 1

The first experiment was designed to expand our understanding of time, speed and distance concepts by overcoming some of the methodological limitations of Piaget's experiments. In order to determine more accurately the sequence of partial understandings leading to mastery of the three concepts, as well as to specify the order of mastery, a task was created that would allow comparable assessment of the three concepts. Children were shown two electric trains on parallel tracks. The two trains could start from the same or different points, could stop at the same or different points, and could go the same or different distances. They could start at the same or different times, could stop at the same or different times, and could travel for the same or different total time. Finally, they could go the same or different speeds. This allowed the creation of completely parallel time, speed, and distance problems. The trains would go different distances at different speeds, for different amounts of time, and the children could be asked, "Which train went (for the longer distance)(faster)(for the longer time)?"

The child's knowledge of each concept was assessed using the rule assessment methodology (Siegler, 1976; 1978a; 1978b; Note 1; Klahr & Siegler, 1978; Siegler & Vago, 1978). This methodology has been shown effective on a large range of problems, including balance scale, projection of shadows, probability, fullness, and conservation tasks. It is based upon two assumptions; that cognitive development can be characterized as a set of increasingly sophisticated rules, and that problem sets can be designed to unambiguously discriminate among these rules.

Piaget's research on time and speed suggested three possible rules. Children using Rule I would rely solely on the stopping points of the trains. Those using Rule II would rely on stopping points unless they were equal, in which case starting points would also be considered. Those using Rule III would solve the problems in an adult fashion, by considering only starting and stopping times. Six problem-types were chosen which would allow discrimination of these rules as well as of the 7 physical dimensions (time, speed, distance, end point, end time, beginning point, and beginning time) on which the child might base his judgments. These problem-types are illustrated in Table 1. To limit the difficulty of the problems, total time, speed, and distance were never equal for the 2 trains.

Twelve individuals in each of 4 age groups (5-, 8-, 11-year-olds, and adults) were used as subjects. The apparatus (illustrated in Figure 1), included two electric trains on parallel tracks. The speed of each train was controlled by a transformer, and the travel time by a Hunter timer. By controlling speed and time, distance traveled by the trains could also be controlled. The problem set consisted of 24 problems, 4 versions of each of the 6 problem-types.

Each child was brought individually to the experiment room on three different days and was asked to judge on each trial which train went faster, for more distance, or for more time. Only one concept was tested on a given day. For a child to be judged to be using a rule, the answers to at least 20 of the 24 problems were required to conform to that rule (for a more detailed description of the procedure, cf. Siegler & Richards, 1979).

Results

Distance concept. Forty-one of the 48 subjects were classified as using a rule on the distance concept problems. As shown in Table 2a, 15 used Rule I, 4 used Rule II, and 22 used Rule III. The remaining subjects' performances most closely approximated Rule III, but did not meet the criterion for rule usage. Rule usage was age related; 5-year-olds used Rules I or II, 8-year-olds used Rule I most often and Rule III occasionally, 11-year-olds used Rule III most often, and adults always used Rule III.

Speed concept. Thirty-eight of the 48 subjects were classified as using a rule on the speed concept problem. As shown in Table 2b, 7 used Rule I, 6 used Rule II, and 22 used Rule III. Rule usage was again related to age; 5-year-olds used Rules I or II, 8-year-olds divided between Rule III and no rule, and 11-year-olds and adults consistently used Rule III.

Time concept. Thirty-two of the 48 subjects were classified as using a rule on the time concept problems. As shown in Table 2c, 7 used Rule I, 6 used Rule II, 5 used a rule based on the total distance traveled (the distance rule), and 13 used Rule III. Five-year-olds most often used Rule I or II, 8-year-olds generally did not meet any rule criterion, 11-year-olds usually used the distance rule or could not be classified as using any particular rule, and adults used Rule III.

The youngest and oldest subjects reasoned at similar levels on all three concepts. Six of the 10 five-year-olds who could be classified as using a rule on all three concepts used the same rule, Rule I or II, on all of them. Adults performed consistently correctly (used Rule III) on all of the concepts. Unlike the 5-year-olds and the adults, 8- and 11-year-olds did not use similar reasoning on all three concepts. Instead, as suggested by the rule usage data (Table 2), they appeared to master both the speed and distance concepts long before mastering the time concept.

As previously mentioned, 16 subjects on the time concept, 10 on the distance concept, and seven on the speed concept did not meet any rule criterion. Examination of the protocols of these subjects revealed distinctly non-random patterns of responses. To clarify the approaches they were taking, multiple regression analyses were performed for each task. The number of errors on each test item served as the dependent variable, and total time, total distance, average speed, end point, end time, beginning point, and beginning time as independent variables. All independent variables were treated as dichotomous except the conceptual variable itself, which was constructed from the ratio of the two travel times, speeds, or distances for each problem.

Most of the errors made by the "no rule" subjects could be accounted for by a small number of variables. For the time concept, the status of the distance variable accounted for 67% of the variance. None of the other variables added as much as 5% to the variance that could be accounted for. On the distance concept, the greatest amount of variance was accounted for by the status of the time variable, although here the speed variable and the distance ratio also added significantly to the accounted for variance. On the speed concept, the distance variable w[illegible] important (60% of the variance) but the end point variable add[illegible] significantly to the regression also.

To summarize, two questions were addressed by this study: what are the knowledge states leading to the understanding of time, speed, and distance, and in what order are the 3 concepts mastered. With regard to the first question, it appears that, as Piaget suggested, 5-year-olds equate time, speed, and distance with the relative stopping points of moving objects, while adults possess full understanding of the three concepts. However, little support was found for Piaget's account of the transition period. The direct predecessors of Rule III appear to be knowledge states in which the concepts are partially understood but still confusable. For the time concept, the state before mastery [illegible] to be one in which time and distance are only partially differentiated. This conclusion was supported both by the use of the distance ru[illegible] by 11-year-olds and by the regression analysis of the people who did n[illegible] eet the rule usage criterion. There was a similar confusion on the distance concept, where time appeared as the largest interfering factor in the regression analysis. On the speed concept, distance and end point appeared to be the most important interfering factors.

In answer to the second question posed by this experiment, an examination of Table 2 shows that substantial numbers of children mastered both the speed and the distance concepts by age 8 and the majority mastered both by age 11. In contrast, the time concept appears to be mastered some time between age 11 and adulthood.

Having obtained a reasonably detailed description of [illegible] quence of knowledge states leading to mastery of these concepts, [illegible] question arose: To what extent could we use these rule assessments [illegible] ability to respond to different types of training? To ad[illegible] question, the second experiment was performed.

Experiment 2

For Experiment 2, the same apparatus was used as in E[illegible]riment 1: two electric trains running along parallel tracks. Five- [illegible] 10-year-olds were used as subjects. A three-part procedure was followed, consisting of a pretest, feedback training, and a posttest.

Pretest. In the pretest phase, children were given a problem set similar to the one used in Experiment 1 but shorter, and were classified according to the rules they used to decide which train ran for more time. Forty 5-year-olds and forty 10-year-olds were selected for further participation. The 5-year-olds were chosen on the basis of their reliance on the end point cue: they needed to answer at least 15 of the 17 pretest problems as predicted by Rule I or Rule II to be included. The 10-year-olds were selected on the basis of their reliance on the distance cues. However, these children were not as firm and consistent in their responses as the younger ones. In order to obtain a sufficient number of older subjects, it was necessary to adopt a less strict criterion. The ten-year-olds who answered at least 11 of the 17 problems as predicted by the distance rule and whose performance was fit better by the distance formula than by any other model were chosen for training.

Feedback training. Ten children of each age were assigned to each of four feedback conditions: end point instruction, distance instruction, distance and end point instruction (hereafter referred to as D & E), and control. Children in all four groups were told whether they were right or wrong immediately following their judgments on each of the 18 problems. All of the instruction sets were constructed so that between 6 and 12 of the 18 problems discriminated speed, end time, beginning time, and beginning point from total time. The other two cues, end point and distance, were discriminated from total time as indicated below.

A) End point instruction- The children assigned to the end point instruction group were presented with a feedback problem set designed to discriminate the end point cue from time. An example of such a problem is presented in Table 3a. The defining attribute is that end point but not distance is discriminated from time: that is, using end point to judge time would lead to an incorrect answer, but using distance would lead to a correct one.

B) Distance instruction- The children assigned to the distance instruction group were given a problem set designed to discriminate the distance cue from time (Table 3b). Such problems would not discriminate end point from time. Thus, children using distance to judge time would be consistently incorrect, but those using end point would be consistently correct.

C) D & E instruction- The children in this group were given problems such as the one illustrated in Table 3c -- problems which discriminated both distance and end point from time. Children who used either distance or end point to judge time would be incorrect on these problems.

D) Control- The control group received problems such as the example in Table 3d. These problems discriminated neither distance nor end point cues from time; all three always led to the correct answer.

Posttest. On the day following training, all participants were given a posttest similar to the pretest to determine which rules the children were using.

Results

Pretest. As in Experiment 1, multiple regression analyses were conducted for the pretest error data using the 7 cues listed previously as independent variables. Regressions were calculated for all children pretested in each age group and also for the 40 individuals in each age group who were selected for assignment to training groups. As Table illustrates, for the total group of 5-6-year-olds tested, end point was the only important interfering cue, accounting for 88% of the error variance. The end point cue accounted for 98% of the variance in error rate for the 40 children selected for further training. Among all of the 10-year-olds screened, distance was the most important predictor of error rate (64% of the variance), but end time was also a significant factor. Of the 40 children selected for further training, distance accounted for 90% of the variance in error rates. Note that even among the selected groups, distance was not as good a predictor of error rate for 10-year-olds as end point was for 5-year-olds.

Posttest. Rule usage on the posttest is summarized in Table 5. Among the younger children, the end point discriminating/non-end point discriminating contrast was the most theoretically interesting. Fourteen of the 20 children in the non-end point discriminating groups continued to use Rule I after training, while only 3 of the 20 children in the end point discriminating groups did. For the older children, the distance discriminating/non-distance discriminating contrast was the important one. Six children in the former groups and two in the latter continued to use the distance rule after feedback training. More striking, four of the 20 subjects in the former groups and 11 of the 20 in the latter groups advanced to Rule III, the correct time rule.

These rule usage data indicate that problems where end point is shown to be a misleading cue are most effective in persuading 5-year-olds to abandon their end point rule, while problems where distance is shown to be misleading are most effective in persuading 10-year-olds to abandon the distance cue. This supports out original hypothesis that differential effects of training can be predicted for children with different original knowledge states.

Because of the large number of children who met no rule criterion on the posttest, regression analyses were performed on the errors made by members of each training group. Again, the 7 possible cues were used as independent variables, and the number of errors made on each item as the dependent variable. As can be seen in Table 6, among 5-year-olds in the distance training and control groups, the end point cue accounted for 94% of the variance in errors. This percentage was about the same as that observed before training. By contrast, for the end point and D & E groups, where end point and time were discriminated, end point accounted for only 14%. Distance becomes the best single predictor of variance in errors, accounting for 36% of the variance. Among 10-year-olds in the end point training and control group, distance is the major predictor variable and accounts for 81% of the variance after training: again, this is substantially the situation that existed before training. However, for the two training groups where the distance cue is discriminated from time, the variance accounted for by the distance factor drops to 48%, and the end time and the time ratio factors add considerably to the regression.

An additional question arises concerning the optimal form of training: which is more effective, demonstrating that all rules but the time rule are incorrect (as D & E instruction does), or demonstrating that the child's existing end point rule is incorrect but leaving open the more advanced but still incorrect distance rule (as end point instruction does). In order to answer this question, regression analyses were conducted individually for each of the four groups of five-year-olds. The results of these regressions are presented in Table 7. As might be expected, for the end point training group the distance cue becomes the most significant predictor of errors. Deprived of their favored cue, end point, 5-year-olds appear to switch their attention to distance. For children in the D & E training group, who are deprived of both the end point cue (their favored one), and the distance cue (which they turn to in the absence of end point), no significant predictor of errors emerges.

Thus teaching the concept of time directly by discriminating it from both distance and end point cues appears to be less effective for the younger children than teaching to the next state of partial understanding the children would normally acquire. When shown that end point is an insufficient cue, 5-year-olds begin to utilize the distance cue just as older children do after they discard end point. If deprived of both the cue they favor and the cue they would normally favor next, 5-year-olds do not become adult time rule users. Instead they fail to use any discernable rule.

Returning to the original hypothesis of this experiment, we conclude that it is possible to predict differences in children's ability to acquire new knowledge once we can specify their initial knowledge. Five-year-olds who are influenced by end point cues abandon this strategy when given training problems where end point cues are discriminated from time. Ten-year-olds who are influenced by distance cues profit from training problems where the distance cue is discriminated from time. The degree of discrimination on other dimensions (speed, beginning point, etc.) does not seem to influence either age group. The generally cleaner effect of training for the five-year-olds appears to be due to the higher quality of the initial assessments of their knowledge; their performance fit the end point characterization much better than older children's fit the distance characterization. This emphasizes that ability to predict learning depends greatly upon the quality of the assessment of the existing knowledge.

Further research in this area will be designed to test whether children actually encode the information necessary to make adult time judgments (in this case, the necessary information is beginning and end time). Five- and 10-year-olds will be questioned to see if they are aware of which train started or stopped first in time. If they are not encoding this essential information, attempts will be made to train the children to do so and the effects of such training will be tested on subsequent time comparison ability.

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Reference Note

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Figure 1: Schematic Diagram of Experimental Apparatus

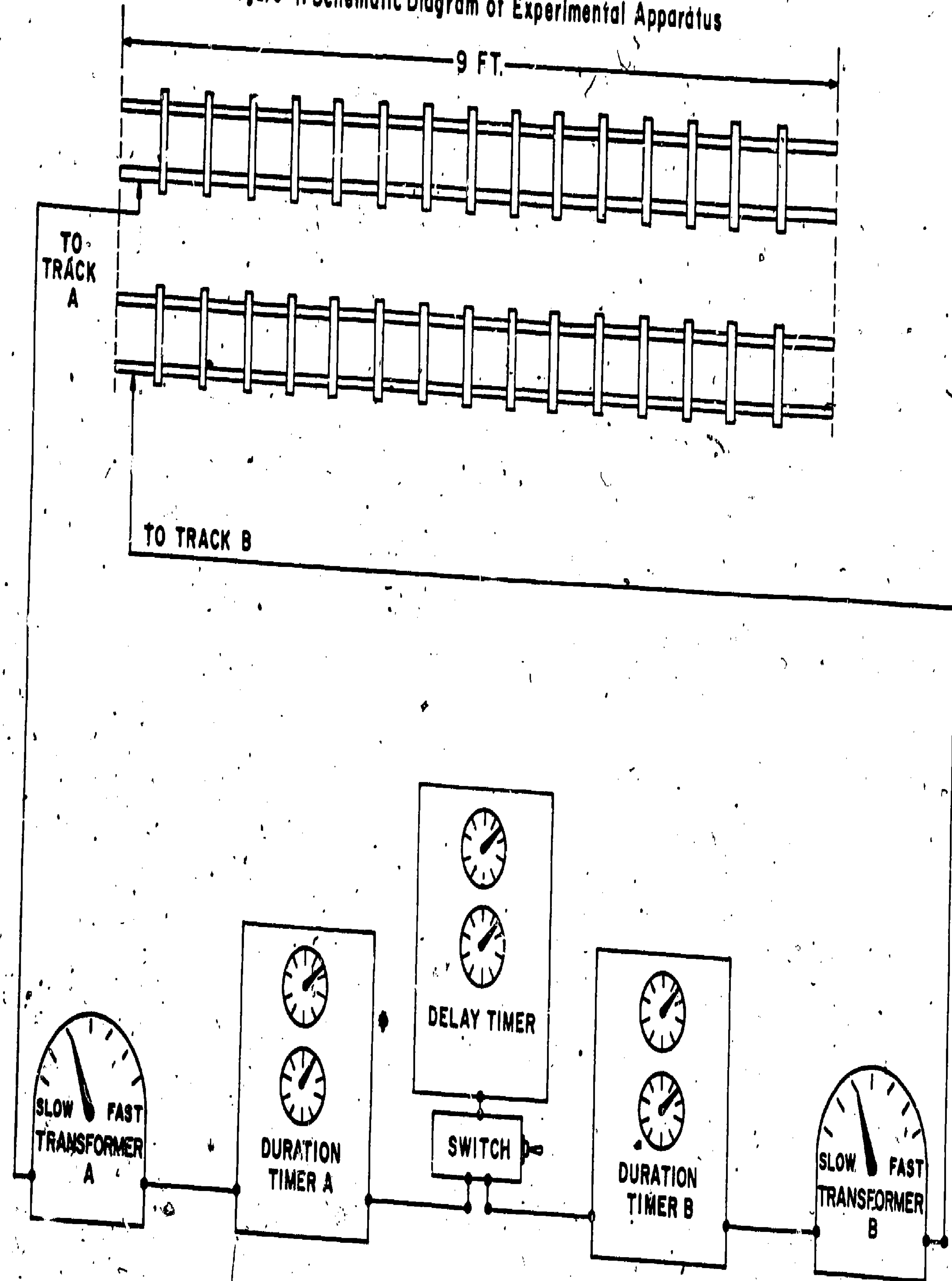


Table 1

Specific Response and Percentage of Correct Answers Predicted by Each Rule for Each Problem-Type on Time, Distance, and Speed Concepts

	Problem-Type[a] 1	2	3	4	5	6
Train A.	0____6	0____9	0__9	0__6	0____6	0____5
Train B.	2____6	0___5	4½____9	0___5	0__4	2__5
Time Concept						
Rule I	"A longer" (100)[b]	"Equal" (0)	"A longer" (100)	"B longer" (0)	"A longer" (100)	"B longer" (0)
Rule II	"A longer" (100)	"A longer" (100)	"A longer" (100)	"B longer" (0)	"A longer" (100)	"B longer" (0)
Rule III	"A longer" (100)	"A longer" (100)	"A longer" (100)	"A longer" (100)	"A longer" (100)	"A longer" (100)
Distance Concept						
Rule I	"A longer" (100)	"Equal" (0)	"A longer" (0)	"B longer" (100)	"A longer" (100)	"B longer" (0)
Rule II	"A longer" (100)	"A longer" (100)	"A longer" (0)	"B longer" (100)	"A longer" (100)	"B longer" (0)
Rule III	"A longer" (100)	"A longer" (100)	"B longer" (100)	"B longer" (100)	"A longer" (100)	"A longer" (100)
Speed Concept						
Rule I	"A faster" (0)	"Equal" (0)	"A faster" (0)	"B faster" (100)	"A faster" (100)	"B faster" (0)
Rule II	"A faster" (0)	"B faster" (100)	"A faster" (0)	"B faster" (100)	"A faster" (100)	"B faster" (0)
Rule III	"B faster" (100)	"B faster" (100)	"B faster" (100)	"B faster" (100)	"A faster" (100)	"A faster" (100)

[a]Numbers in the problems correspond to the number of seconds since the beginning of the trial. Lengths and relative positions of lines correspond to distances travelled and spatial positions. Thus, in the example in problem-type 1, one train (A) would start at the beginning of the trial and travel for six seconds, while the other (B) would start two seconds after the trial began and would also stop at second six. The two trains would start from parallel points, but Train A would finish farther up the track.

[b]Numbers in parenthesis refer to predicted percentage of correct answers.

Table 2

Number of Children Using Each Rule

		Rule Used				
		I	II[a]	Distance	III	No Rule
A. Distance Concept						
	5-6	6	4	0	0	2
Age	8-9	6	0	0	3	3
Group	11-12	3	0	0	7	2
	Adult	0	0	0	12	0
B. Speed Concept						
	5-6	6	6	0	0	0
Age	8-9	1	0	0	4	7
Group	11-12	0	0	0	10	2
	Adult	0	0	0	11	1
C. Time Concept						
	5-6[b]	6	4	0	0	1
Age	8-9	1	2	0	0	9
Group	11-12	0	0	5	2	5
	Adult	0	0	0	11	1

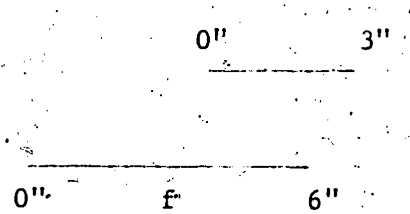
[a]The numbers of children using Rule II refer to the revised Rule II in which children judge on the basis of stopping times when end points are equal.

[b]One child used the speed rule on the time concept.

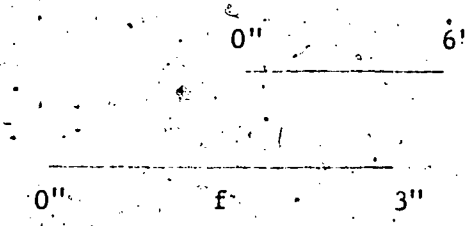
Table 3

Training Problems

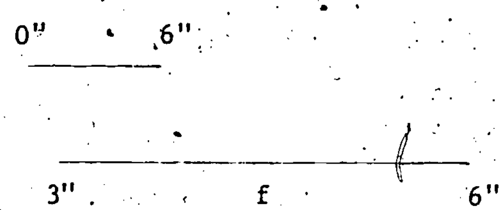
A. Discriminates End Point



B. Discriminates Distance



C. Discriminates Distance and End Point



D. Discriminates Neither End Point Nor Distance

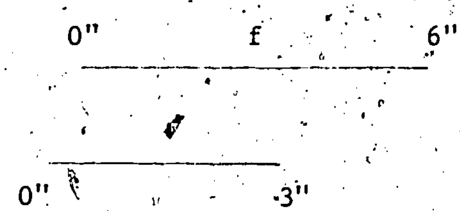


Table 4

Percentage of Variance Accounted for by Predictor Variables on Pretest

	Group	Predictor Variable(s)	Variance Accounted For
Five-Year-Olds	Total	1 End Point	88%
	Selected	1. End Point	98%
Ten-Year-Olds	Total	1. Distance	64%
		2. Distance + End Time	85%
	Selected	1. Distance	90%

Table 5

Rule Usage on Posttest

	Rule			
	End Point	Distance	Time	None
5-year-olds				
Control	8	0	0	2
Distance	6	0	1	3
End Point	3	0	1	6
Distance & End Point	0	0	2	8
10-year-olds				
Control	0	4	2	4
End Point	0	2	2	6
Distance	0	1	5	4
Distance & End Point	0	1	6	3

Table 6

Percentage of Variance Accounted for by Predictor Variables on Posttest

	Instruction Group	Predictor Variable(s)	Variance Accounted For
Five-Year-Olds	Distance and Control	1. End Point	94%
	D & E and End Point	1. Distance	36%
		2. Distance + Beginning Point	48%
		3. Distance + Beginning Point + End Point	59%
Ten-Year-Olds	End Point and Control	1. Distance	81%
		2. Distance + End Time	93%
	D & E and Distance	1. Distance	48%
		2. Distance + End Time	66%
		3. Distance + End Time + Ratio of Times	82%

Table 7

Percentage of Variance Acc
for by Predictor Variables on est

5-year-olds

Instruction Group	Predictor Variable(s)	Variance Accounted For
Control	1. End Point	98%
Distance	1. End Point	85%
	2. End Point and End Time	91%
End Point	1. Distance and Beginning Point	56%
D & E	--------	--